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September 30, 2003

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APPLICATION NUMBER: 60/464,872

FILING DATE: April 23, 2003

10/03/4070

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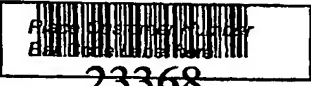
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## PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EV 242302815 US

| INVENTOR(S)   |  |                           |     |   |  |
|---|--|---------------------------|-----|---|--|
| Given Name (first and middle [if any])  |  | Family Name or Surname    |     | Residence<br>(City and either State or Foreign Country)                             |  |
| Petrus A.   |  | Besselink                 |     | The Netherlands   |  |
| <input type="checkbox"/> Additional inventors are being named on the _____ separately numbered sheets attached hereto                     |  |                           |     |   |  |
| TITLE OF THE INVENTION (500 characters max)   |  |                           |     |   |  |
| VASCULAR FILTER WITH IMPROVED STRENGTH AND FLEXIBILITY  |  |                           |     |   |  |
| Direct all correspondence to: CORRESPONDENCE ADDRESS  |  |                           |     |   |  |
| <input checked="" type="checkbox"/> Customer Number   |  | 23368                     |     |  |  |
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| Country   |  | Telephone                 | Fax |   |  |
| ENCLOSED APPLICATION PARTS (check all that apply)   |  |                           |     |   |  |
| <input checked="" type="checkbox"/> Specification Number of Pages   |  | 35                        |     | <input type="checkbox"/> CD(s), Number  |  |
| <input checked="" type="checkbox"/> Drawing(s) Number of Sheets   |  | 5                         |     | <input type="checkbox"/> Other (specify)  |  |
| <input checked="" type="checkbox"/> Application Data Sheet. See 37 CFR 1.76   |  |                           |     |   |  |
| METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT  |  |                           |     |   |  |
| <input checked="" type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27.  |  |                           |     | FILING FEE AMOUNT (\$)  |  |
| <input checked="" type="checkbox"/> A check or money order is enclosed to cover the filing fees   |  |                           |     | 80.00   |  |
| <input type="checkbox"/> The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: |  |                           |     |   |  |
| <input type="checkbox"/> Payment by credit card. Form PTO-2038 is attached.   |  |                           |     |   |  |
| The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.   |  |                           |     |   |  |
| <input checked="" type="checkbox"/> No.   |  |                           |     |   |  |
| <input type="checkbox"/> Yes, the name of the U.S. Government agency and the Government contract number are: _____                        |  |                           |     |   |  |

Respectfully submitted,

SIGNATURE

TYPED or PRINTED NAME John D. Reed

TELEPHONE (937) 223-2050

Date 04/23/03

REGISTRATION NO.  
(if appropriate)  
Docket Number:

46,506

BES 0009 M4

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This collection of information is required by 37 CFR 1.51. The information is used by the public to file (and by the PTO to process) a provisional application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the complete provisional application to the PTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, Washington, D.C. 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Box Provisional Application, Assistant Commissioner for Patents, Washington, D.C. 20231.

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**FEE TRANSMITTAL  
for FY 2003**

Effective 01/01/2003. Patent fees are subject to annual revision.

☒ Applicant claims small entity status. See 37 CFR 1.27**TOTAL AMOUNT OF PAYMENT** (\$)**80.00****Complete if Known**

|                      |                     |
|----------------------|---------------------|
| Application Number   |                     |
| Filing Date          | April 23, 2003      |
| First Named Inventor | Petrus A. Besselink |
| Examiner Name        |                     |
| Art Unit             |                     |
| Attorney Docket No.  | BES 0009 M4         |

**METHOD OF PAYMENT (check all that apply)**☒ Check ☐ Credit card ☐ Money Order ☐ Other ☐ None☐ Deposit Account:

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☐ Charge any additional fee(s) during the pendency of this application  
☐ Charge fee(s) indicated below, except for the filing fee to the above-identified deposit account.
**FEE CALCULATION****1. BASIC FILING FEE**

| Large Entity        |          | Small Entity |          | Fee Description        | Fee Paid                |
|---------------------|----------|--------------|----------|------------------------|-------------------------|
| Fee Code            | Fee (\$) | Fee Code     | Fee (\$) |                        |                         |
| 1001                | 750      | 2001         | 375      | Utility filing fee     |                         |
| 1002                | 330      | 2002         | 165      | Design filing fee      |                         |
| 1003                | 520      | 2003         | 260      | Plant filing fee       |                         |
| 1004                | 750      | 2004         | 375      | Reissue filing fee     |                         |
| 1005                | 160      | 2005         | 80       | Provisional filing fee | 80.00                   |
| <b>SUBTOTAL (1)</b> |          |              |          |                        | <b>(\$)<b>80.00</b></b> |

**2. EXTRA CLAIM FEES FOR UTILITY AND REISSUE**

| Total Claims       | Extra Claims | Fee from below | Fee Paid |
|--------------------|--------------|----------------|----------|
| Independent        | -20** =      | X              |          |
| Multiple Dependent | -3** =       | X              |          |

| Large Entity |          | Small Entity |          | Fee Description  |
|--------------|----------|--------------|----------|--|
| Fee Code     | Fee (\$) | Fee Code     | Fee (\$) |  |
| 1202         | 18       | 2202         | 9        | Claims in excess of 20                                     |
| 1201         | 84       | 2201         | 42       | Independent claims in excess of 3                          |
| 1203         | 280      | 2203         | 140      | Multiple dependent claim, if not paid                      |
| 1204         | 84       | 2204         | 42       | ** Reissue independent claims over original patent         |
| 1205         | 18       | 2205         | 9        | ** Reissue claims in excess of 20 and over original patent |

**SUBTOTAL (2)** (\$)**-0-**

\*\*or number previously paid, if greater; For Reissues, see above

**FEE CALCULATION (continued)****3. ADDITIONAL FEES**

| Large Entity |          | Small Entity |          | Fee Description  | Fee Paid |
|--------------|----------|--------------|----------|--|----------|
| Fee Code     | Fee (\$) | Fee Code     | Fee (\$) |  |          |
| 1051         | 130      | 2051         | 65       | Surcharge - late filing fee or oath  |          |
| 1052         | 50       | 2052         | 25       | Surcharge - late provisional filing fee or cover sheet                     |          |
| 1053         | 130      | 1053         | 130      | Non-English specification  |          |
| 1812         | 2,520    | 1812         | 2,520    | For filing a request for <i>ex parte</i> reexamination                     |          |
| 1804         | 920*     | 1804         | 920*     | Requesting publication of SIR prior to Examiner action                     |          |
| 1805         | 1,840*   | 1805         | 1,840*   | Requesting publication of SIR after Examiner action                        |          |
| 1251         | 110      | 2251         | 55       | Extension for reply within first month                                     |          |
| 1252         | 410      | 2252         | 205      | Extension for reply within second month                                    |          |
| 1253         | 930      | 2253         | 465      | Extension for reply within third month                                     |          |
| 1254         | 1,450    | 2254         | 725      | Extension for reply within fourth month                                    |          |
| 1255         | 1,970    | 2255         | 985      | Extension for reply within fifth month                                     |          |
| 1401         | 320      | 2401         | 160      | Notice of Appeal   |          |
| 1402         | 320      | 2402         | 160      | Filing a brief in support of an appeal                                     |          |
| 1403         | 280      | 2403         | 140      | Request for oral hearing   |          |
| 1451         | 1,510    | 1451         | 1,510    | Petition to institute a public use proceeding                              |          |
| 1452         | 110      | 2452         | 55       | Petition to revive - unavoidable   |          |
| 1453         | 1,300    | 2453         | 650      | Petition to revive - unintentional   |          |
| 1501         | 1,300    | 2501         | 650      | Utility issue fee (or reissue)   |          |
| 1502         | 470      | 2502         | 235      | Design issue fee   |          |
| 1503         | 630      | 2503         | 315      | Plant issue fee  |          |
| 1460         | 130      | 1460         | 130      | Petitions to the Commissioner  |          |
| 1807         | 50       | 1807         | 50       | Processing fee under 37 CFR 1.17(q)  |          |
| 1808         | 180      | 1808         | 180      | Submission of Information Disclosure Stmt                                  |          |
| 8021         | 40       | 8021         | 40       | Recording each patent assignment per property (times number of properties) |          |
| 1809         | 750      | 2809         | 375      | Filing a submission after final rejection (37 CFR 1.129(a))                |          |
| 1810         | 750      | 2810         | 375      | For each additional invention to be examined (37 CFR 1.129(b))             |          |
| 1801         | 750      | 2801         | 375      | Request for Continued Examination (RCE)                                    |          |
| 1802         | 900      | 1802         | 900      | Request for expedited examination of a design application                  |          |

Other fee (specify)

\*Reduced by Basic Filing Fee Paid

**SUBTOTAL (3)** (\$)**-0-****SUBMITTED BY**Name (Print/Type) **John D. Reed**Registration No.  
(Attorney/Agent)**46,506**

(Complete if applicable)

Telephone **(937) 223-2050**

Signature

Date

**April 23, 2003****WARNING:** Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

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## IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application of

Applicants : Petrus A. Besselink

Title : VASCULAR FILTER WITH IMPROVED STRENGTH AND FLEXIBILITY

Docket No. : BES 0009 M4

## BOX PROVISIONAL PATENT APPLICATION

Assistant Commissioner for Patents  
Washington, DC 20231

Sir:

EV242302815US

**"Express Mail" Mailing Label Number EV 242302815 US****Date of Deposit April 23, 2003****I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the BOX PROVISIONAL PATENT APPLICATION, Assistant Commissioner for Patents, Washington, DC 20231.**  
Melody Tolliver  
Legal Secretary

JDR/mjt

**Initial Information Data Sheet****Inventor Information**

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**Application Information**

**Title Line One::** VASCULAR FILTER WITH IMPROVED STRENGTH  
**Title Line Two::** AND FLEXIBILITY  
**Total Drawing Sheets::** 5  
**Formal Drawings?::** Yes  
**Application Type::** Provisional  
**Docket Number::** BES 0009 M4

**Representative Information**

**Registration Number One::** 26,397  
**Registration Number Two::** 27,262  
**Registration Number Three::** 29,001  
**Registration Number Four::** 39,564  
**Registration Number Five::** 38,769  
**Registration Number Six::** 33,758  
**Registration Number Seven::** 42,695  
**Registration Number Eight::** 46,867  
**Registration Number Nine::** 46,506  
**Registration Number Ten::** 46,458  
**Registration Number Eleven::** 52,364

**Continuity Information**

**This application is a::**

**> Application One::**

**Filing Date::**

**Provisional of**

**60/423,240**

**11/01/02**

**which is a::**

**> Application One::**

**Filing Date::**

**Provisional of**

**60/417,408**

**10/09/02**

**which is a::**

**> Application Two::**

**Filing Date::**

**Provisional of**

**60/412,071**

**09/19/02**

## **VASCULAR FILTER WITH IMPROVED STRENGTH AND FLEXIBILITY**

### **BACKGROUND OF THE INVENTION**

This invention relates to membranes for vascular filters with improved strength and flexibility compared to the filters that are now on the market. The filters make use of a proximal frame section and a distal section, made of a flexible thin membrane with perfusion holes of a diameter that allows blood to pass, but prevents the movement of emboli downstream.

Both sections can be collapsed into a small diameter delivery catheter and expanded upon release from this catheter. The distal filter membrane has a proximal entrance mouth, which has almost the same size as the body lumen. It is attached to the proximal section, which has the function to keep the mouth of the distal filter open and prevent the passing of emboli between the body lumen wall and the edge of the filter mouth.

The reinforced membranes can also be used for parts of catheters, like for example inflatable parts, balloon pumps, replacement of body tissues, repair of body parts and functional parts like artificial valves and membranes.

This application relates to the field of producing an expandable frame with a membrane that is placed in a body lumen, like for example an improved distal filter for protection against emboli, which can migrate during angioplasty/stenting procedures.

In US provisional application 09/803,641 and US 2001/0044634 A1 a double filter system was described with a distal filter and a second, proximal filter that closes the entrance of the distal filter before it is collapsed in order to be removed.

In US 5,885,258 a retrieval basket for catching small particles was disclosed, made from a slotted nitinol tube. The pattern of the slots allows expansion of the nitinol basket and by shape setting (heat treatment in the desired unconstrained geometry) this basket is made expandable and collapsible by means of moving it out or into a surrounding delivery tube.

In principle a distal filter is made of such an expandable frame that defines the shape and enables placement and removal, plus a filter membrane or mesh that does the actual filtering work.

Sometimes the expandable frame and the mesh are integrated and made from a single material, for example Nitinol, like in US 6,383,205 or US 2002/0095173. These filters do not have a well-defined and constant size of the holes where the blood flows through, because of the relative movement of the filaments in the mesh. This is a disadvantage, because the size of emboli can be very critical, e.g. in procedures in the carotid arteries. Further the removal of such a filter, accompanied by a reduction of the diameter, may be disadvantageous because emboli can be squeezed through the mesh openings with their changing geometry.

A much better control of the particle size is achieved with a separate membrane or filter sheath, which has a well-defined hole pattern with for example holes of 100 microns, attached to a frame that takes care of the correct placement and removal of the filter.

In WO 00/67668 a Nitinol basket forms the framework of the filter, and a separate polymer sheath is attached around this frame. At the proximal side the sheath has large entrance ports for the blood and at the distal side a series of small holes filters out the emboli.

This system, however, has some major disadvantages. First of all, the closed basket construction makes this filter frame rather rigid and therefore it is difficult to be used in strongly tortuous arteries. In a curve it may even not fit well against the artery wall and cause leakage along the outside of the filter.

Another disadvantage of such filters is there is a high risk of squeezing-out the caught debris upon removal, because the struts of the framework force the debris back in proximal direction, while the volume of the basket frame decreases when the filter is collapsed. Further the construction makes it very difficult to reduce the profile upon placement of the filter. This is disadvantageous, because these filters have to be advanced through critical areas in the artery, where angioplasty and/or stenting are necessary. Of course the catheter that holds this filter should be as small as possible then. In the just described filter the miniaturization will be difficult, because at a given cross section there is too much material. The metal frame is surrounded by polymer and in the center there is also a guide wire. During angioplasty and



stenting the movements of the guide wire will further create forces, which influence the position and shape of the filter, which may cause problems with the proper sealing against the artery wall. This is also the case in strongly curved arteries. It would be good if the guide wire could freely move in tangential, axial, and radial direction through the cross section area where the filter is placed, without influencing the position and shape of the filter.

In US 6,348,062 the frame is placed proximal and the distal polymer filter membrane has the shape of a bag, attached to one or more frame loops, forming an entrance mouth for the distal filter bag. Here the bag is made of a very flexible polymer and the hole size is well defined. Upon removal the frame is closed, thus closing the mouth of the bag and partly preventing the squeezing-out of debris. This is already much better than for the full basket design, which was described above, where the storage capacity for debris of the collapsed basket is relatively small.

The filter bag is attached to the frame at its proximal end and sometimes to a guide wire at its distal end. Attachment to the guide wire can be advantageous, because some pulling force may prevent bunching of the bag in the delivery catheter.

It may be clear that it is easier to pull a flexible folded bag through a small diameter hole, than to push it through. However, the deformation of the bag material should stay within certain limits, and it would be excellent if these limits would be controllable.

If the filter is brought into a delivery sheath of small diameter, collapsing the frame and pulling the bag into the delivery sheath causes rather high forces on the connection sites of filter to frame and/or guide wire. While the metal parts of the frame slide easily through such a delivery sheath, the membrane material may have the tendency to stick and in the worst case it may even detach from the frame, tear upon placement or during use, just because of too much friction, unlimited expansion, crack propagation etc.

The connection of the filter bag to the frame is rather rigid, because of the method of direct attachment. Additional flexibility, combined with a high strength attachment spot would also be advantageous.

To overcome the strength problem, the membrane may be made thicker, but this makes the overall size also larger and thus the crossing profile. If the membrane is relatively thick, the blood flow through the holes will of course also be less than in the case where the holes are made in an extremely thin membrane.

Methods for making kink resistant reinforced catheters by embedding wire ribbons are described in PCT/US93/01310.

A mandrel is coated with a thin layer of encapsulating material. Then a means (e.g. a wire) for reinforcement is deposited around the encapsulating material and eventually a next layer of encapsulating material is coated over the previous layers, including the reinforcement means. Finally the mandrel is removed from the core of the catheter.

Materials for encapsulating are selected from the group consisting of polyesterurethane, polyetherurethane, aliphatic polyurethane, polyimide, polyetherimide, polycarbonate, polysiloxane, hydrophilic polyurethane, polyvinyls, latex and hydroxyethylmethacrylate.

Materials for the reinforcement wire are stainless steel, MP35, Nitinol, tungsten, platinum, kevlar, nylon, polyester and acrylic. Kevlar is a Dupont product, made of long molecular highly oriented chains, produced from poly-paraphenylene terephalamide. It is well known for its high tensile strength and modulus of elasticity.

In US 09/537,461 the use of polyethylene with improved tensile properties is described. It is stated that high tenacity, high modulus yarns are used in medical implants and prosthetic devices. Properties and production methods for polyethylene yarns are disclosed.

US 5,578,374 describes very low creep, ultra high modulus, low shrink, high tenacity polyolefin fibers having good strength retention at high temperatures and methods to produce such fibers. In an example the production of a poststretched braid, applied in particularly woven fabrics is described.

In US 2001 0034197 oriented fibers are used for reinforcing an endless belt, comprising a woven or non-woven fabric coated with a suitable polymer of a low hardness

polyurethane membrane, in this case to make an endless belt for polishing silicon wafers. Examples are mentioned of suitable yarns like meta- or para-aramids such as KEVLAR, NOMEX OR TWARON; PBO or its derivatives; polyetherimide; polyimide; polyetherketone; PEEK; gel-spun UHMW polyethylene (such as DYNEEMA or SPECTRA); or polybenzimidazole; or other yarns commonly used in high-performance fabrics such as those for making aerospace parts. Mixtures or blends of any two or more yarns may be used, as may glass fibers (preferably sized), carbon or ceramic yarns including basalt or other rock fibers, or mixtures of such mineral fibers with synthetic polymer yarns. Any of the above yarns may be blended with organic yarns such as cotton.

Disclosure of reinforcement of thin membranes with fibers for the use in filters is not found in the known literature.

#### SUMMARY OF THE INVENTION

This invention relates to vascular filters with improved strength and flexibility compared to the filters that are now on the market. The filters make use of a proximal and a distal section, which can be collapsed into a small diameter delivery catheter and expanded upon release from this catheter. The proximal section is made as a frame of a relatively rigid material, for example a metal and the distal section is made of a flexible thin membrane with perfusion holes of a diameter that allows blood to pass, but prevents the movement of emboli downstream. The distal filter membrane has a proximal entrance mouth, which has almost the same size as the body lumen. It is attached to the proximal section, which has the function to keep the mouth of the distal filter open and prevent the passing of emboli between the body lumen wall and the edge of the filter mouth.

In order to have a good flexibility and a minimized crossing profile upon delivery the membrane is made extremely thin. Normally this would create the risk that the membrane could tear easily, which could cause big problems because emboli and pieces of the membrane would then be taken downstream from the filter site. This problem is overcome by embedding the filter membrane with thin filaments of a material with high strength in longitudinal direction, but high flexibility upon bending. Such a composite filter membrane can have extreme flexibility and elasticity in certain directions, combined with limited deformation, high strength and prevention of crack propagation through the membrane

material. Further the filaments can be attached to the proximal frame in such a way that the connection points act as hinges and as additional safety for the case that the membrane material might come loose from the frame.

Another function of the embedded filaments is that they help to give the membrane a desired shape after deployment.

A method for producing such filters is also disclosed.

The surface of the membrane filter may be coated with some additional material that improves the properties, for example the biocompatibility, drugs release or any other desired property, which the membrane itself does not offer.

Another object of the invention is that the reinforced membranes can also be used for parts of catheters, replacement of body tissues, repair of body parts and functional parts like artificial valves and membranes, where minimal thickness and/or high strength are required.

Fibers are not only used as reinforcement for the membranes, but are also used as pull wires for the retrieval of an expandable frame into a removal sheath. Such frames can be used in temporary devices like a removable temporary stent, dilator, reamer, occlusion device for main artery or side artery, a housing for a graft, a valve, a delivery platform for drugs, radiation or gene therapy or any other device that has to be placed and removed after some time. Applications are not restricted to arteries, but are meant for all body lumens.

Further a method for producing filters by dipping on a removable mold is disclosed.

#### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The principles of the disclosed invention become clear in the following description of the figures. Identical parts in different figures are mentioned with the same number.

The principles of the disclosed invention become clear in the following description of the figures. Identical parts in different figures are mentioned with the same number.

Figure 1 shows a paraffin mold 1, made in the desired filter shape. Paraffin is chosen, because it can be removed from the filter easily, at a temperature that does not cause degradation of the polyurethane of the filter.

However, dipping of polyurethane directly to the paraffin is not giving good results and a thin layer of polyvinylalcohol 2 surrounds therefore this paraffin mold. The polyvinylalcohol is a thin sheet that can be stretched after wetting with water and pulled tight around the paraffin and then tied together with a small clip or wire 3. Then it is dipped a few times in a solution of polyurethane in tetrahydrofuran, thus building a layer of polyurethane of e.g. 3 microns at the right side of the dipping line.

Figure 2 gives a nitinol frame 20, made from tubing with outer diameter 0.8 mm by laser cutting and shape setting. At the proximal side, which is on the left, the tube end 25 is uncut and still 0.8 mm. in diameter. From there eight longitudinal spokes 26 run until they end in a zigzag section with struts 27, where the unconstrained, expanded diameter is 8 mm at its largest size. This frame 20 will, at any size between the maximum diameter and the collapsed size of 0.8mm diameter, always adapt smoothly to the given geometry of the artery. In this frame the mold of figure 1 is placed and eight wires of a reinforcement fiber 28 of for example multifilament ultra high molecular weight polymer are attached to the most distal section of the nitinol frame 20 at points 29. These fibers can be attached to the nitinol by means of a knot or they can just be wrapped around the nitinol struts and run back and forth from the distal tip to the strut ends 29.

At the distal tip all fibers come together in a guide ring or tube 30, where they are held in correct position for the further dipping.

Figure 3 shows how the mold with the nitinol frame and the surrounding fibers have been dipped a few more times until the fibers are well embedded in the polyurethane, for example until the layer polyurethane is 5 microns thick at the places 31 where no reinforcement fibers 28 are. Of course the thickness at the places 32, where these fibers are, is larger than at places 31, dependent of the type of fibers and the amount of dipping steps. Guide tube 30. of figure 2 has been removed after the dipping was finished and the membrane was dry.

Figure 4 shows the final filter 40, with a pattern of holes 41 of 100 micron diameter, which has been laser drilled between the reinforcement fibers 28 and after that the central paraffin mold has been removed by melting in warm water of 50 degrees celsius. The polyvinylalcohol layer easily released from the polyurethane filter membrane and was removed. Further the fibers 28 have been cut to the correct length at point 42 and attached to the central guide wire 43 in a nose tip 44 that fits on top of the delivery catheter if the filter is withdrawn into this catheter before placement into the body lumen of the patient. Note that the polyurethane between the nitinol struts was also removed at the proximal side of the struts 27, preferably by laser cutting.

This construction is extremely strong and still very flexible. The 5 microns thick membrane with the reinforcement fibers 28 fits easily in a delivery catheter of only 0.9 mm inner diameter and adapts to all sizes of arteries between 1 and 8 mm diameter.

The central guide wire 43 helps to pull the filter membrane out of the delivery catheter, and all tension force is taken up by the reinforcement fibers 28. The membrane only has to follow these fibers and unfold as soon as it leaves the catheter. The filter opens because of the elasticity of the nitinol frame and also because the blood pressure even helps it further to open like a parachute. Upon bending there is almost no force needed at the sites where fibers are attached to the nitinol struts, so these sites act as hinges. Even in strongly curved arteries the filter frame still adapts well to the wall and there is almost no blood leaking between membrane and artery wall.

The fibers are so well embedded in the polyurethane, that in case the polyurethane detaches from the nitinol struts, the membrane will still have a strong connection to the frame and can be collapsed and removed from the patient safely.

In case of a tear in the membrane, for example starting from a 100 micron hole, this membrane may tear further, but only until the crack meets a fiber. There the crack will stop, and the membrane can be removed safely and completely as well. (Of course this situation is very undesirable and the loss of some entrapped emboli may be the consequence, but at least the removal of the filter itself does not cause problems).

After the procedure the nitinol frame can be collapsed to close the mouth of the filter and entrapped emboli can not leave this closed filter bag anymore. The hinges guarantee now that the filled bag hangs at the distal end of the removal catheter and still can move easily through curved arteries.

The reinforcement wires are not only used for their high tensile strength. Nitinol wires can be shape set to almost any desired shape by heat treatment. Such wires may be embedded in or attached to the membrane to guarantee a smooth folding/unfolding of the membrane. An example is an embedded nitinol wire that helps to give the mouth of the filter membrane a smooth geometry that fits well to the artery wall. Such a nitinol wire for shape control can be combined with a more flexible, but stronger fiber, which is used to protect the membrane against incidental overload, crack propagation or any of the described problems in non-reinforced membranes.

Orientation and amount of the reinforcement fibers are not limited and vary with the application.

In figure 5 a distal filter 50 is given, with a conical shaped filter membrane 51, attached to the same proximal wire frame 20 as in figures 2- 4. In this example, however, the membrane is not dipped directly to the nitinol frame. It is attached by guiding for example the reinforcement fiber 52 from the distal end 53 under an angle with the cone surface until it reaches the nitinol struts 27 at points 29, than wrapped around these struts at points 29 and guided back to the distal tip with a reverse angle. Arrows in the drawing show how fiber 52 runs back and forth. By this method the use of knots at the fiber-nitinol connection is redundant and the safety is further increased, because the filter can never detach from the frame.

The pattern with crossing reinforcement fibers gives the filter membrane different elastic properties and gives the benefit of an improved, but limited axial elasticity.

The pattern of filter holes, preferably cut by laser, can be made between the fiber zones to stay away from damaging the fibers.

However, if the pattern of reinforcement fibers is very fine, the holes may just be cut without looking at the position of these fibers. There will than still be enough reinforcement left, just because adjacent crossing, parallel or angled uncut fibers can take over some forces via the embedding material of the membrane itself.

The cone design has the following advantages. If this filter has a maximum diameter of 8 mm and if it is placed in an artery of 8mm diameter, all holes will be free from the artery wall and blood can flow through all holes. As soon as particles of debris, like emboli, are entrapped, they will tend to collect at the most distal tip, leaving the more proximal holes open.

The surface area of the flanges of the cone relates to the cross section area of the artery as the length of the cone edge from base to tip relates to the radius of the artery. Preferably, the accumulated surface area of the holes should be at least equal to the cross section area of the artery in order to guarantee an almost undistorted blood flow. This is the case if the relation between the total surface area of cone surface to total accumulated hole surface area is smaller than the relation between cone surface area and cross section area of the artery.

For an 8mm artery a total amount of 6400 holes with 100 microns diameter is needed for a same surface area. Of course the type of flow through small 100micron holes is different from the undistorted flow of an open artery.

However, because the wall thickness of a reinforced membrane according to this invention can be extremely small, the length of a hole (for example only 5 microns) ensures a much better flow than compared to a 100 micron hole in a thick membrane.

A filter made in conical shape will also have enough free holes if it is used in arteries with smaller diameter. The holes that touch the artery wall will not anymore contribute to the flow, but the remaining free holes still have the same surface area as the actual cross section of the (smaller) artery.

Filters according to this invention are so much more flexible than existing filters, that they can be made longer without creating problems in strong curves. Therefore they can have more storage capacity for emboli.



If the reinforced membrane and the filter frame are mounted to each other without overlap, like in figure 5, it may be clear that the collapsed diameter can be made smaller than in the case of for example figure 4.

Here, at a specific cross section of the nitinol frame near the attachment points 29, the nitinol, the membrane, the fibers and a central guide wire are all taking their part of the available cross section in the delivery sheath. It depends on the demands if this is allowable, or that a design is chosen without overlap, where frame and membrane are separated by the fiber hinges, thus reducing the size.

The construction of nitinol frame 20 has certain advantages. The production of the frame is very simple, the guide wire is kept in the center, and the filter can be pushed out of the delivery sheath, eventually with the help of additional pull force through the reinforced membrane.

Upon removal of the filter the longitudinal spokes 26 of frame 20 just have to pull the struts 27 of the zigzag section into a removal sheath.

However, such a frame can also have some disadvantages. In strongly curved arteries the guide wire will bend and it will cause forces that may deform the zigzag struts. Eventually the contact with the wall of the artery is not optimal then, which is undesirable.

Another disadvantage is that axial movements of the guide wire, for example caused by the angioplasty/stenting procedure will influence the position of the filter. It would be better if the guide wire could move freely over at least a certain axial length plus in radial and tangential direction within the entire cross section of the filter, without exerting any force on the expanded frame.

In figures 6-9 an embodiment with such a free movable guide wire is disclosed.

Figure 6 shows a filter 60 that is constructed in such a way that it is delivered from a delivery sheath by pulling it out, instead of pushing. After the procedure it is removed by

pulling it into a removal sheath as well. The pull forces are applied in both directions by moving the guide wire in axial direction relative to the sheath.

Guide wire 61 runs through the filter and ends at distal section 62. At the guide wire are stops 63 and 64, that have a larger diameter than the guide wire itself. These stops are connected tightly to the wire by any known technique. At the distal tip of the filter 60 a ring 65 is mounted, where the guide wire can slide through freely, until stop 63 touches this ring 65.

At the proximal side of stop 64 a second slide ring 66 is mounted around guide wire 61. Slide rings 65 and 66 have been given a smooth shape with rounded edges to let the move easily in the sheaths and in the artery.

The filter membrane 70 is connected directly to slide ring 65 and reinforcement wires 71 are also attached tightly to this ring. At the other side reinforcement wires 71 are connected to expandable frame 80 at connection points 81, eventually together with the membrane material itself.

Expandable frame 80 is provided with points of attachment 82 at its proximal side, which are needed to pull the frame back into a removal sheath. Fibers 83 are connected to these points 82 and run to the proximal slide ring 66, onto which they are also tightly attached.

If the guide wire is moved through the filter in proximal direction, stop 64 will move freely over a distance  $X_1$  before it touches slide ring 66 and fibers 83 become stretched.

If the guide wire is moved through the filter in distal direction, stop 63 will move freely over a distance  $X_2$  before it touches slide ring 65. Fibers 83 will hang free than, because there is no axial force on slide ring 66. This means, when the filter has been placed in an artery, that the guide wire can move freely in the cross section area of the filter frame in both radial and tangential direction without exerting any forces onto this frame. Further the guide wire can also move back and forth over a total distance ( $X=X_1+X_2$ ) in longitudinal direction relative to the filter, before it influences its shape or axial position in the artery. Distance  $X$  can be enlarged by choosing the distance between fixed stops 63 and 64. If one of

these stops is removed distance X is maximized. Of course the distal end section 62 of guide wire 61 must then be long enough to prevent that slide ring 65 disengages from the guide wire tip.

With the construction of slide rings 65 and 66 on guide wire 61 this guide wire can be rotated around its length axis without influence to the position and shape of the filter and its frame.

All these degrees of freedom enable the operator to use guide wire 61 for the angioplasty/stenting procedure without influencing the shape and position of the distal filter. This is extremely important.

Further this design shortens the length of the nitinol frame and thus it makes the filter more flexible and easier usable in strongly bent arteries and arteries with limited parking space for the filter. In a strongly curved artery the guide wire 61 may even touch the inner wall of frame 80, without exerting relevant forces to the filter. Even with such a strongly bent guide wire the filter will still maintain its full contact with the artery wall and guarantee a safe functioning of the device for a wide range of artery diameters and geometries.

As can be seen if figure 6 is compared with figures 4 and 5, the design of figure 6 gives a much smaller proximal surface of the expanded frame. In figures 2-5 the nitinol spokes 26 and the proximal side of tube section 25 have a certain surface area that reduces blood flow. This surface area is much smaller in figure 6, because only a few thin fibers 83 are hanging in the blood flow.

Another advantage is that debris in the blood will less likely adhere to the thin fibers than to the proximal side of parts 25 and 26. Of course an additional treatment of these fibers to reduce the tendency of blood cells to adhere to these fibers is helpful and is a part of this invention as well. The material for these fibers can be of any kind, and they can for example made of the same materials as the reinforcement wires for the filter membrane.

An example would be a composite fiber made of a nitinol core, surrounded by a multifiber ultra high molecular weight highly oriented polymer. The nitinol can be used to give some shape control to the wire, for example to prevent that adjacent fibers get entangled.

The polymer multifilament enables besides high strength and low strain the embedding with for example anti-thrombogenic agents.

In figure 7 the filter of figure 6 is shown while it is being delivered from a delivery sheath 90. This sheath has a wall 91 and a distal end 92. At the proximal side of the guide wire 61 a pushing force F is applied into distal direction, while sheath 90 is pulled back into proximal direction. Stop 63 on guide wire 61 is now in direct contact with slide ring 65, and force F is brought over by this ring to the reinforcement fibers 71 of the filter membrane 70. By the resulting pulling force in the filter membrane plus fibers 71 the filter membrane is stretched and this pulling force is brought over to the collapsed frame 80 via connection points 81. Frame and filter membrane will easily slide out of the sheath by this pulling force, followed by the unloaded fibers 83 and slide ring 66. As can be seen the proximal section 82 of frame 80, where the fibers 83 are attached to, is slightly bent inwards to create a conical proximal side of frame 80.

Figure 8 shows the filter while it is removed by means of removal sheath 100. Removal sheath 100 has a wall 93 and a distal end 94. At distal end 94 the removal sheath may have a flared end section 95, like in insert figure 8a, a tapered wall 96 like in insert figure 8b or a combination thereof. This distal end must enable the retrieval of the filter into the lumen of sheath 100 by a pulling force, which is applied to the proximal end of guide wire 61 while sheath 100 is moved into distal direction. The tapered proximal side 82 of the frame also helps to move the frame into the removal sheath.

The force F1, applied to guide wire 61, is brought over by stop 64 to slide ring 66, which distributes the force to fibers 83 that are now pulling to the proximal side 82 of frame 80. The wire ends are attached by any technique that is available, for example by putting them through the respective holes 84, and secure them by a knot 85 on the inside surface of the frame. The proximal tips 86 have been made in such a way that they are slightly curved inside with a conical top angle that is larger than the top angle of the cone, described by the stretched fibers 83, just before the parts 86 enter into removal sheath 93. This is done to prevent that these proximal sections get stuck at the distal end 94 of the removal sheath.

With the tapered shape of frame 80 the tension force in fibers 83 will easily make it possible to slide the removal sheath over the frame until it is completely covered by this

sheath. Filter membrane 70, eventually filled with emboli debris, does not have to be pulled into this sheath completely. It can hang at the distal end 94, while the whole device is removed from the artery.

Figure 9a and 9b show an alternative embodiment 110 of the filter frame, in its expanded and collapsed shape respectively. The frame is now not made as a series of full unit cells, like in figures 6-8, but as half unit cells, connected in a zigzag-pattern. Here again the proximal side 112 is tapered with curved tips 116 and it has attachment holes 114 for the fibers.

The fact that the filter frame does not anymore have to be delivered with pushing force in its struts enables a further downscaling of these struts and thus a miniaturization of the delivery profile of the device. This is also enhanced by the fact that the guide wire does not influence the shape and position of the filter upon angioplasty and stenting, so the frame itself can now also be made lighter.

In the insert of figure 10 another embodiment of the filter frame 120 is given. Elongated struts 126 are connected to the proximal side 112 of the frame 120 in order to bring the holes 124 for the attachment of the fibers 83 further away from the expandable and collapsible unit cells of the frame. This increased length helps to achieve a more smooth shape upon shape setting, so that these struts will get the desired curvature that is needed to slide easily into the removal sheath. Placement of the attachment holes at the very proximal tip of these struts will also help to pull the frame back into the removal sheath, without the risk of getting stuck at the entrance of this sheath.

The elongated struts 126 can be shape set into almost any desirable angle. A part of the struts may be parallel with the length axis of the filter, while other parts may be angled inside or outside, just what is needed for smooth removal of the device. Outside angled tips may even help to anchor the frame into the vessel for more axial stability.

Figure 11 shows another feature of the present invention. The design with flexible fibers 83 makes it possible to push a tube 130 over guide wire 61 until the distal end 131 of tube 130 reaches deep into the filter.

The fibers 83 will easily move with the distal end of this tube 130, and dependant on the length of these fibers the most distal position of tube end 131 can be chosen. This positioning of a tube inside or beyond the frame 120 opens the possibility of flushing and/or suction through it in order to move debris either deeper into the distal tip of the filter or to suction debris out of the filter. Flushing with certain liquids can also help to make debris smaller. Eventually an additional treatment device can be inserted through tube 130 inside the filter. This treatment device can be any means for inspection, measuring or all kinds of treatments like breaking up of clots by mechanical means, laser, ultrasonics or the like. Also additional retrieval devices may be brought into the filter through tube 130. Of course tube 130 may be the same tube as the removal sheath, in order to save components and to reduce operating time.

Figure 12 gives another embodiment for the shape of a filter 70, with an additional reservoir 72 for storage of debris. Because the conical filter of figures 6-11 has a tip with limited space to store debris, the filter may be filled too soon, which may cause problems with maintaining a satisfactory blood flow through it.

Normally it can be expected that major part of the debris will collect most distally, leaving the most proximal holes open for blood flow. This can be improved by additional reservoir 72, which is connected to the conical section 73 by an area 74. If the diameter of reservoir 72 is half the size of the diameter of the frame, the surface area that remains free for blood flow between the wall of the full reservoir and the artery wall is still 75% of the maximum surface area of the artery. The capacity of the reservoir can be chosen so that the closure of filter holes in section 73 by abundant debris is most unlikely. Additional flushing and/or suction like in figure 11 may further help here. Of course the continuous monitoring of the blood flow beyond the distal end of the filter will give the necessary information if the situation becomes critical and the filter must be removed.

Shape and diameter of the reservoir will be dependent on the expected diameter and geometry of the artery that will be treated. The shape of the reservoir can be determined by embedded fibers. The membrane may for example be elastic, while the fibers have a limited strain. Dependent on the pressure inside the reservoir the diameter of the membrane can vary until it reaches a certain predetermined value, when the embedded fibers reach their strain limit. Such embedded diameter limiting fibers will have a more or less tangential orientation.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The advantages of the invention will become more apparent after reference to the following description, wherein some embodiments are elucidated.

In the present invention a filter with improved flexibility and smaller profile is described. The filter basically has a proximal frame for expansion and contraction and attached thereto a thin filter bag which basically exists out of minimal two materials. One material is the highly flexible filter membrane itself, with a pattern of holes for allowing flow of blood particles below a well defined size, and the other material is a reinforcement made of fine fibers with high axial strength but thin enough to be flexible upon bending. The reinforcement is integrated with the membrane to create a composite structure with very flexible membrane areas where the blood is filtered and extremely strong reinforcement fibers that take up excessive forces, control the shape of the filter and act as flexible hinges at the points of attachment to the proximal frame and/or the guide wire.

These fibers can be embedded in the membrane by a dipping or spraying process or they can be attached with glue, stitching, a solvent for the membrane material, heat, welding etc.

In order to get a better connection between the reinforcement fibers and the membrane material the fibers may first be coated with a material that adheres well to the membrane material, for example with the same material.

Fibers can be made of any strong and tough material, preferably a material with a modulus of elasticity that is much higher than for the surrounding membrane. It can be made of round, flat or different shaped mono-filaments or multi-filaments and it can be based on metal, for example titanium or Nitinol, carbon, boron, glass, or polymers, for example ultra high molecular weight polymers with extreme tensile strength and high modulus.

The fibers not only reinforce the membrane, but also can be used to control the final geometry, stop crack propagation, act as hinges at the place of attachment to the frame and prevent loss of the membrane or parts of it.

Because of the reinforcement the membrane itself can be made much thinner, so the crossing profile of the composite filter can be much lower than for a single polymer membrane, even if the reinforcement fibers are much thicker than the membrane itself.

A method for making such a reinforced filter is also disclosed. A paraffin mold is prepared into the desired shape of the filter bag and then it is provided with a polymer skin, which easily detaches from the membrane polymer. This paraffin mold is dipped in a solution of polymer and solvent until a layer of membrane polymer is created.

After that step the mold is attached to the frame and the coated reinforcement fibers are then mounted to the frame at the hinge sites and laid over the surface of the mold. Another dipping step then ensures full embedding of the fibers into the growing membrane polymer layer.

Finally the hole pattern is laser drilled into the membrane and the last step is the removal of the paraffin by melting it out in warm water. The polymer skin easily detaches from the inside of the filter membrane and is pulled out.

With the use of a paraffin mold it is possible to make complicated or very simple designs, because there is no need to remove a relatively large mandrel from the filter after it has been made. This would be complicated if the mandrel was for example a metal or polymer part, which had to be pulled through some openings at the proximal side.

Paraffin is of course not the only material that can be used for a mold. Any material that can be brought into the desired shape and which can be directly dipped or with an intermediate layer may be used. Examples are meltable materials or materials that easily dissolve in water, like salt or sugar crystals. Other examples are fine grains in a vacuum bag or an inflated balloon which is deflated after dipping.

Fibers are also used for enabling the removal of expandable devices by means of pulling them into a removal sheath.

It will be appreciated by those skilled in the art that other applications of reinforced membranes and/or removable frames are possible. For example, the removable frame as



disclosed in figures 6-12 may not only be used in application of filters. It can also be used as a removable temporary stent, dilator, reamer, occlusion device for main artery or side artery, a housing for a graft, a valve, a delivery platform for drugs, radiation or gene therapy or any other device that has to be placed and removed after some time. Applications are not restricted to arteries, but are meant for all body lumens. These and the following examples are meant to be a part of this invention as well.

In addition, the reinforced membranes can also be manufactured without holes for use for parts of catheters, inflatable parts, balloon pumps, replacement of body tissues, repair of body parts and functional parts like artificial valves and membranes, where minimal thickness and/or high strength are required. Dependent on the application the membrane is completely closed, semipermeable or provided with holes for filtering function or improvement of cell ingrowth. Holes in the membrane can further be used to store drugs, which are slowly released from the membrane. Further holes can be used for attachment to surrounding frames or tissues. Of course the hole pattern can be applied before, during or after the procedure of embedding the fibers.

Reinforcement fibers not only improve the strength of a membrane; they also can prevent stress degradation and improve the fatigue properties of heavy loaded membranes, like in a heart valve. Fibers are used not only as reinforcement for the membranes, but are also used as pulling fibers for the extraction of the device from a delivery catheter or for retrieval, or retraction, of the device into a removal sheath. The frames can be used in temporary devices like a removable temporary stent, dilator, reamer, occlusion device for main artery or side artery, a housing for a graft, a valve, a delivery platform for drugs, radiation or gene therapy, or any other device that has to be placed and removed after some time.

As described for the filter, pulling fibers are also used to influence the relative position between an expandable frame with an attached reinforced membrane and a surrounding delivery or removal sheath. For the filter a set of pulling fibers is used to pull the frame in or out of the sheath, but in alternative devices a single pulling fiber may be sufficient. Such a fiber may be actuated directly by the operator, or indirectly by the guide wire, like with the stop as described in the filter design.

Further, the invention provides a method for producing devices such as graft stents, drug delivery devices, filters by dipping on a removable mold. According to this method, thin filaments of a material with high strength in the longitudinal direction, but high flexibility upon bending, are embedded in the filter membrane. In most cases additional expandable frames, e.g. made of nitinol, are attached to these membranes. After attachment of the fibers to the frames, the dipping creates a strong, but very flexible device with a high expansion ratio. This means that the crossing profile of such a device can be smaller than for non-reinforced devices with a thicker polymer membrane without reinforcement. The fibers are preferably less stretchable than the membrane material. The resulting composite membrane can have extreme flexibility and elasticity in certain directions, combined with limited deformation, high strength and prevention of crack propagation through the membrane material. Another function of the embedded filaments is that they help to give the membrane a desired shape after deployment.

The shape and diameter of an inflatable device will be dependent on the expected diameter and geometry of the artery that will be treated. The shape of the device can be determined by embedded fibers. The membrane may for example be elastic, while the fibers can have a limited ability to stretch. Dependent on the pressure inside the reservoir, the diameter of the membrane can be made to vary until it reaches a certain predetermined value, when the embedded fibers reach their strain limit. Such embedded diameter limiting fibers will have a more or less tangential orientation.

The following examples serve to further highlight the applicability of the present invention.

#### **Compliant balloon with expansion limit**

Normally balloons for angioplasty and/or stenting are made of non-compliant material, because they can be inflated to high pressures without an undesirable amount of increase of the diameter. Once the inflated state is reached, the additional increase in diameter is limited. A disadvantage of the non-compliance is that such a balloon has a folded surface after deflation. In order to minimize the diameter of such a deflated balloon this surface has to be folded very accurate and still the profile may be rather large. Another disadvantage of the folds is that upon inflation the folded flaps will unfold in an unsymmetrical and uneven way, so the deployment of a stent, mounted on such a balloon, will not occur in a smooth way.

With a compliant balloon, which is able to maintain a circular cross-section during all its stages of inflation and deflation, the expansion of a stenosis and/or stent will be much smoother. However, compliancy means that increase in pressure will automatically mean increase in diameter. After reaching the wall of the body lumen the increase of balloon diameter should stop or at least become less if the pressure is further raised.

This can be achieved by surrounding the balloon with a non-compliant element, which limits the further diameter increase. Such a non-compliant element can be simply made by applying a fiber around the balloon after it has been inflated to its desirable maximum diameter. Such a fiber can for example be dipped in glue and then wrapped around the balloon surface to reinforce this balloon surface. Alternatively, the fiber pattern is first wrapped around the surface and then the balloon plus fibers are simultaneously dipped in a polymer solution that creates a layer on the balloon surface.

The fibers do not necessarily have to be applied on an existing balloon surface. They can also directly be integrated with the balloon surface when this is produced.

Such a layer with embedded fibers should be extremely thin and flexible, in order to be sure that upon deflation the balloon can return to its previous small diameter and still maintain a circular cross section. Therefore the use of fibers with high axial strength, but with very high flexibility upon bending makes such a design work well. It may be clear that the orientation and distribution of the fiber pattern on the balloon should be chosen so that it will give enough support to the underlying compliant balloon layer. This is important because at high pressures the compliant surface, which is not directly covered by reinforcing fibers should not stretch too much in any of radial, tangential or axial directions.

#### **Balloon pumps**

The same principle as described above can be used for balloon pumps with a compliant balloon including strain limiting fibers, attached to or embedded in the surface of this balloon. Balloon pumps are used for cardiac assist, where a balloon is placed in the aorta to help improve the pumping capacity. With embedded fibers the balloon can be given a gradient in diameter upon inflation, thus causing a kind of peristaltic movement.

### **Repair of body parts**

Reinforced membranes as described can further be used to replace or repair natural membranes. Examples are closure of holes in a natural membrane, like a hole in the wall between heart chambers, or a hole in the diaphragm. Attachment of such a reinforced membrane to the surrounding natural tissue can be easier because stitching directly with or to the embedded fibers is more reliable than to an un-reinforced membrane, which tears out sooner. Dependent on the application the reinforced membrane may have a pattern of holes, like in the described filter, be semi-permeable or be not permeable at all.

### **Heart valve**

A reinforced membrane can be used as an artificial heart valve with a polymer surface and reinforcement fibers embedded therein on specific places, like the stronger and thicker sections in a natural heart valve tissue, which attach the heart valve to the surrounding tissue.

In this embodiment the fibers not only reinforce the artificial membrane, but they also enable a proper attachment to the valve housing and with a proper orientation they will control the shape of the membrane and limit its elasticity.

In heart valves, made of unreinforced polymers, problems with fatigue can occur. Often degradation of the polymer under stress causes failure. Reinforcement by fibers, according to the invention, prevents degradation and thus improves the fatigue properties.

### **Stent grafts**

In stent grafts a proper pattern of reinforcement fibers can take up all high mechanical forces and improve the fatigue properties, while the membrane itself can be very thin and only serves as a matrix for these fibers. The thickness of the membrane can be minimized, which improves the expansion ratio of the stent and minimizes the crossing profile.

The surface of the reinforced membrane graft may be treated with drugs eluting layer, antithrombogenic agents or any other coating which improves the biocompatibility or functionality. Such a device may also be used as a delivery platform for radiation or gene therapy.

An example of an embodiment of the invention is a reinforced graft membrane, which is attached to two expandable frame rings, like the rings as described in the filter application. Such rings can be connected directly to the reinforcing fibers and eventually they may be made removable by means of the pulling fibers as described for the filter.

#### **Occlusion grafts**

A stent graft, reinforced with fibers, can be used to close an aneurysm or a side artery. Basically such an occlusion device can be made of two or more expandable rings and an elongated, more or less cylindrical reinforced membrane graft in between these rings. Closure of a side artery or aneurysm is achieved by positioning one ring proximally of the section to be closed and one ring distally, with the reinforced membrane in between. The reinforcement prevents rupture of the graft wall at the location of the aneurysm or side artery.

Eventually an occlusion device can also close the main artery. In such a case a device can look like the described filter with a single expandable frame, but without holes in the membrane surface. The single frame ring, which is holding the graft in place, can be placed before the critical cross section, where the closure is needed. The occlusion grafts can of course be made removable in the same way as the filter, by using a removal sheath and pull fibers to retrieve the frame plus graft into the sheath.

#### **Complicated stents**

According to the same principle as explained above for occlusion grafts, more complicated stents can be made, like e.g. AAA-stents. Three or more expandable frame rings, attached to a web of reinforcement fibers, which are mounted on a mandrel or mold, can be easily embedded in a polymer membrane by dipping, spraying or any available technique. After removal of the mandrel or mold an extremely flexible, but strong graft stent with high expansion ratio is the result. Again, combination with pulling fibers for placement and/or removal is an option. The thin membrane allows miniaturization of medical devices for applications like in the brain, where very thin arteries need stenting, grafting or aneurysm closure.

#### **Reinforced bag for manipulating matter**

In US 6,447,523 B1 a membrane bag is described, which is attached to an expandable wire frame that can be collapsed or expanded by means of a remote actuator. The bag is used

to remove cut-away tissue from the mammalian body and its entrance is closed before pulling the device out. Reinforcement of the membrane by means of embedding fibers and improvement of the attachment of the membrane by mounting the fibers direct to said expandable wire frame is a part of the invention. The risk of tearing of the bag or eventual detachment of the bag from the frame is reduced strongly by the embedded fibers.

### Temporary devices

The invention also comprises the use of pulling fibers, connected to an expandable frame, which are used to pull the frame into the mouth of a removal device. The construction with the elongated struts, like in figures 6-12 for the filter, allows an easy collapse of a temporary device.

In figures 6-12 the temporary device is always connected to the guide wire as long as the pulling fibers remain connected to the proximal slide ring. Eventually it may be necessary to disconnect the pulling wires from the frame or the guide wire. This may be the case if the decision is made that the device has to stay in the lumen for an extended period of time, or eventually becomes permanent.

Such a detachment from the guide wire can be done in several ways. One example is that the pulling fibers are disconnected from the slide ring. This can be done by remote changing of the shape of the slide ring, thus unclamping the pulling fibers from this slide ring. Another possibility is that each pulling fiber has an eyelet at the proximal end, and all these eyelets are connected with a single long fiber, which runs through these eyelets and of which at least one end can be held or released by the operator. If one free end of this long fiber is released, it will slide through all eyelets, thus disconnecting the strut fibers from the guide wire. In another embodiment the fibers can be disconnected by cutting, melting or breaking.

A further possibility is that the fibers remain connected to the ring, but that the ring itself is detached from the guide wire. Figure 13 shows a simple release mechanism, made with a deformable tube which fits in the ring. On a central wire 201 tube 250 is mounted, which at its distal end 253 is provided with two stops 251 and 252, one at the proximal side and one at the distal side of the ring 202. Ring 202 is connected to expandable frame 204 by means of struts or fibers 203. The distal section of tube 250, which holds the stops, is provided with length slots, which enable a local diameter change of tube 250 at its distal end

253. The deformation of tube end 253 can be elastic or plastic. Tube end 253 can for example be made from nitinol and be heat treated to have a reduced diameter in its unstrained state.

If the central wire 210 is located in the tube end, the wire keeps tube end 253 in a cylindrical shape, thus pushing stops 251 and 251 outward in such a way that axial movement of tube 250 causes movement of ring 202. This can be seen in figure 13a, where ring 202 is firmly attached to tube end 253.

In figure 13b, however, wire 201 is pulled back relative to tube 250 until tube end 253 is empty, so it can deform to a smaller diameter, until stops 252 bend enough inward to loose contact with ring 202.

Figure 13c shows how the guide wire, existing from parts 201 and 250, is completely detached from ring 202 and thus from struts/fibers 203 and frame 204.

An alternative for the external stops 251 and 252 can be an elastic pin which pushes through a side hole in the tube wall at the location where ring 202 is mounted. The elastic pin only grips ring 202 as long as it is pushed outward by central wire 201. The rest works the same as described above.

In the situation that a device has two slide rings mounted on the same guide wire, like the filter of figures 6-12, the release mechanism of figure 13 may first be used to place the device while the tube end is in contact with the most distal ring. After releasing this distal ring the wire 201 can be pushed into section 253 of tube 250, to ensure a good grip on the proximal ring 202 while the guide wire is pulled back. If release of the proximal ring is necessary the procedure of pulling back of wire 201 is repeated. In such a way several stages of gripping and release are possible with a single coupling tool and a series of sliding rings.

Temporary devices which may or may not be released according to this invention include filters, occlusion devices, stents, valves, baskets, reamers, dilators, delivery platforms for drugs etc.

#### *Objects of the invention*

It is an object of the invention that the reinforced membrane is completely closed, semi-permeable or provided with a pattern of holes for filtering function, improvement of cell-ingrowth, controlled drugs delivery or attachment purposes.

Still another object of the invention is the use of reinforced membranes in the repair or replacement of body tissues, like the repair or closure of holes in heart chamber, diaphragm, etc.

It is an object of the invention that attachment of such a reinforced membrane to the surrounding natural tissue can be easier because stitching directly with or to the embedded fibers is more reliable than to an un-reinforced membrane, which tears out sooner.

Of course it is also an object of the invention that the reinforcement fibers can be placed in the membrane on specific places, like the stronger and thicker sections in natural heart valve tissue, which attach the heart valve to the surrounding tissue.

Of course it is also an object of the invention that reinforcement fibers are used to prevent stress degradation and to improve the fatigue properties of heavy loaded membranes, like for example in a heart valve.

It is further another object of the invention that a reinforced membrane is used as a compliant balloon with expansion limit, which is able to maintain a circular cross-section during all its stages of inflation and deflation.

In yet another object of the invention a compliant reinforced balloon is used as a balloon pump for cardiac assist.

Another object of the invention is that the cooperation between membrane and the embedded fibers in the reinforced balloon pump causes a peristaltic movement during inflation and deflation.

It is further another object of the invention that reinforced membranes are combined with expandable frame rings to build a complicated stent, like bifurcating AAA-stents or extremely small stents like for neuro-applications.



In yet another object of the invention the reinforcement fibers are used as an improvement of existing devices, where a polymer membrane is attached to expandable frames, like for example the removal bag in US 6,447,523 B1. Reinforcement prevents detachment and allows miniaturization.

Another object of the invention is that pulling fibers are used to influence the relative position between an expandable frame with an attached reinforced membrane and a surrounding delivery or removal sheath.

It is further another object of the invention that the pulling fibers are actuated directly by the operator or indirectly by the guide wire.

In yet another object of the invention the pulling fibers can be detached from the expandable frame or from the guide wire in order to leave this frame in place permanently.

Another object of the invention is that the detachment of the pulling fibers is achieved by disconnecting the fibers from the frame, guide wire or slide ring by cutting, melting, breaking or shape change of the slide ring.

Still another object of the invention is that the detachment of the pulling wires is achieved by release of one free end of a single wire loop that runs through eyelets of all pulling fibers or frame struts.

It is an object of the invention that the slide rings can be released from the guide wire by changing the shape of a mechanical lock at the distal end of guide wire.

Of course it is also an object of the invention that the mechanical lock can collapse as soon as it is not anymore filled with a central wire, which is pulled back to create said shape change by remote control.

Another object of the invention is that temporary devices which may or may not be released include filters, occlusion devices, stents, grafts, valves, baskets, reamers, dilators, delivery platforms for drugs, radiation or gene therapy etc.

It is an object of the invention that the thickness of a membrane with improved flexibility for use in a human body is minimized by the use of a composite material, comprising a thin membrane layer and a reinforcement material to ensure that it keeps enough strength or enable a proper attachment.

It is also an object of the invention that the membrane is attached to a frame to bring and hold said reinforced membrane in the desired shape.

Another object of the invention is that the frame is used to collapse or expand the reinforced membrane.

It is further another object of the invention that the reinforced membrane contains a pattern of holes to let body fluid through, while particles above a predetermined size are not allowed to flow through.

In yet another object of the invention the frame and reinforced membrane are used as a blood filter to prevent emboli above a given size to pass through the device, while the normal blood flow remains intact.

It is also an object of the invention that the blood filter according to this invention is used for distal protection in medical procedures comprising angioplasty and stenting.

Another object of the invention is that the reinforced filter membrane is used outside a patient's body.

Still another object of the invention is that the reinforcement fibers have a relatively high tensile stress and modulus of elasticity, compared to the material of the membrane itself.

It is further another object of the invention that the reinforcement fibers are relatively flexible upon bending.

Another object of the invention is that the reinforcement fibers have such properties that they are suitable to be used to bring and hold the membrane into a desired shape.

Of course it is also an object of the invention that reinforcement fibers of different types are used in the same product, comprising the use of fibers for shape control combined with fibers with high tensile strength.

It is an object of the invention that the reinforcement fibers can be made of a mono-filament or multi-filament and that they can have all kinds of cross sections and orientations.

It is also an object of the invention that the reinforcement wires are coated in a polymer to enhance the adhesion to the membrane material, including the coating with the same polymer.

Another object of the invention is that the coated reinforcement wires are glued to the membrane with a solvent for the given membrane material.

Another object of the invention is that the material, used for the membrane, includes but is not limited to all polymers, organic tissue and tissue from human or animal origin.

It is also an object of the invention that the membrane itself is made as a mesh.

Still another object of the invention is that the material for the reinforcement fibers includes all known materials, comprising carbon, glass, metals, metal alloys, for example nitinol, polymers, including ultra high molecular weight highly oriented polymers or combinations thereof.

It is further another object of the invention that the reinforcement wires can be attached to or in the membrane and to the frame by means of any known technique, including the use of dipping, spraying, welding, glue, stitching, sewing, pressing, heat, light and knotting.

Another object of the invention is that the reinforcement fibers are an integral part of the frame.

It is also an object of the invention that the sites of attachment of reinforcement fibers to the frame act as hinges to increase the flexibility.

It is further another object of the invention that the fibers can stop crack propagation through the membrane and prevent detachment of (parts of) the membrane.

It is an object of the invention that the fibers are distributed over the membrane surface in a specific designed pattern or in a random pattern.

It is also an object of the invention that the holes in the membrane are distributed over the membrane surface in a specific designed pattern or in a random pattern, even if they cut through the reinforcement fibers.

Another object of the invention is that the use of reinforcement fibers makes it possible to reduce the membrane thickness so much that the flow resistance through the holes in the membrane is minimized.

In yet another object of the invention the use of reinforcement fibers makes it possible to reduce the membrane thickness so much that the flow resistance through the membrane wall becomes so small, that it can act as a semi-permeable membrane.

Another object of the invention is the method that comprises preparing a mold of a material with a melting point well below the temperature where the membrane material is damaged, covering the mold with an intermediate material that allows the creation of a membrane surface on it, creating a membrane surface, providing the reinforcement fibers, covering the fibers with another layer of membrane surface, removing the mold by melting or solving and removing the covering of said intermediate material from the membrane surface.

Still another object of the invention is that the mold is made of a material that dissolves in a liquid or that it is made of a sheath, filled with fine solid grains and then vacuum sealed.

Another object of the invention is that the mold is made of an expandable or inflatable structure, which can be removed after dipping but before use.

It is further another object of the invention that the surface of the membrane filter may be coated with some additional material that improves the properties, for example the biocompatibility, drugs release or any other desired property, which the membrane itself does not offer.

It is within the scope of the invention that any material or any combination of materials can be used in any configuration to apply a pattern of reinforcement fibers to the membrane and to the frame.

Still another object of the invention is that the reinforced membranes can also be used for parts of catheters, like for example inflatable parts, balloon pumps, replacement of body tissues, repair of body parts and functional parts like artificial valves and membranes.

Another object of the invention is a filter with enlarged free surface area at the proximal side of the expanded frame, in order to prevent obstruction of the blood flow and to reduce the surface area, occupied by the filter materials at this proximal side, where debris or platelets might adhere to said proximal surface.

It is within the scope of the invention that the proximal section of the expandable frame is connected to the guide wire by means of tension or pulling fibers, which can pull the frame into a removal sheath in order to retrieve it from the lumen of the patient's body.

It is within the scope of the invention that the distal section of the expandable frame is connected to the guide wire by means of tension or pulling fibers, which can pull the frame out of a delivery sheath in order to place it in a lumen of the patient's body.

Still another object of the invention is that the guide wire has at least one section with larger diameter that can be used to apply a force in proximal or distal direction to slide rings which are connected to the filter by means of reinforcement or pulling fibers, membrane material or combinations thereof.

It is also an object of the invention that the pulling fibers are directly attached to a slide ring at one side and to the expandable frame at the other side.

Still another object of the invention is that the proximal section of the removable frame is made slightly tapered to prevent removal problems while the frame is retrieved into the sheath.

It is also an object of the invention that the pulling fibers for retrieval are made of materials comprising all the disclosed materials for reinforcement fibers and combinations thereof.

Another object of the invention is that the pulling fibers are coated with or embedded in a passive or active biocompatible material that prevents the adherence of emboli or platelets, or releases active drugs to the patient's body.

It is within the scope of the invention that the distal end of the guide wire is provided with a pressure sensing tip for continuous monitoring of the blood pressure.

Still another object of the invention is that the guide wire can move freely in the cross section area of the expanded frame in axial, radial and tangential direction as well as upon rotation around its length axis, without influencing the position and shape of the frame.

Another object of the invention is that a filter according to this disclosure is used in a double filter system as described in US 2001/0044634.

It is also an object of the invention that one filter system according this disclosure can be used in body lumens of a wide range of sizes and curvatures.

It is within the scope of the invention that one or each of the disclosed embodiments can also be used as a removable temporary stent, dilator, reamer, occlusion device for main artery or side artery, a housing for a graft, a valve, a delivery platform for drugs, radiation or gene therapy or any other device that has to be placed and removed after some time. Applications are not restricted to arteries, but are meant for all body lumens.

It is an object of the invention that the filter frame has elongated struts at the proximal side to enable easier removal of the frame by pulling the fibers.

Of course it is also an object of the invention that the fibers are connected to these struts by means of attachment holes in the struts or by glue, welding or other techniques.

Another object of the invention is that a proper shape setting of the elongated struts makes removal easier, by giving these struts variable angles relative to the length axis of the device.

It is further another object of the invention that the elongated struts may be used for additional anchoring of the device in order to prevent axial migration in the body lumen.

In yet another object of the invention a tube is advanced over the guide wire until it comes inside the filter for performing additional treatment inside the filter.

Another object of the invention is that the additional treatment inside the filter through said tube comprises suction, flushing, inspection, measuring, or all kinds of treatments like breaking up of clots by mechanical means, laser, ultrasonics etceteras. And further also additional retrieval devices to remove particles from the filter while it stays in place.

Still another object of the invention is that the tube for additional treatment is also used as a removal sheath for the filter.

It is an object of the invention that the filter comprises an additional reservoir for increasing the storage capacity of debris, which improves the maintenance of the blood flow through the filter.

Of course it is also an object of the invention that the diameter of the filter and its reservoir varies over its length to optimise the blood flow and storage capacity.

Another object of the invention is that by flushing the eventual debris, which sticks at the proximal side of the filter, is brought more distally in the filter to improve the capacity and maintain the blood flow through the proximal section.

It is further another object of the invention that by the use of a flexible membrane in combination with reinforcing fibers the filter is made expandable until a given predetermined limit.

Still another object of the invention is that the reinforcing fibers are oriented in such a way that the elastic membrane has a shape that depends of the pressure difference over the membrane, with given predetermined limits.

It will be appreciated by those skilled in the art having regard to this disclosure that other modifications of this invention beyond these embodiments specifically described herein may be made without departing from the spirit of the invention. Accordingly, such modifications are considered within the scope of the invention as limited solely by the appended claims.

I claim:



1. A medical device including one or more of the novel features described in the above specification and drawings.
2. A medical device substantially as described in the above specification and in the accompanying drawings.
3. A vascular filter including one or more of the novel features described in the above specification and drawings.
4. A vascular filter substantially as described in the above specification and in the accompanying drawings.
5. A method of producing a vascular filter that includes one or more of the novel features described in the above specification and drawings.
6. A method of using a vascular filter that includes one or more of the novel features described in the above specification and in the accompanying drawings.

Fig. 1

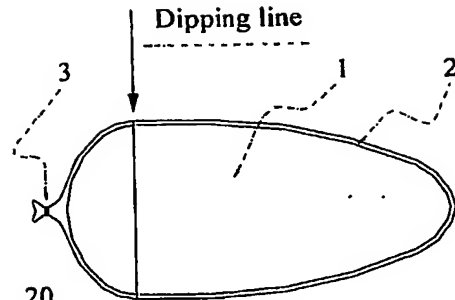


Fig. 2

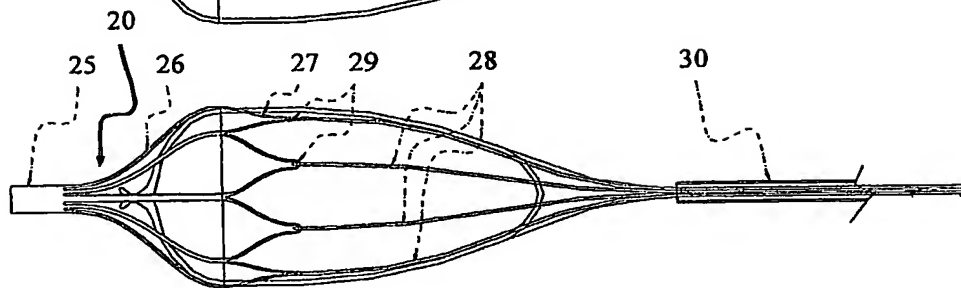


Fig. 3

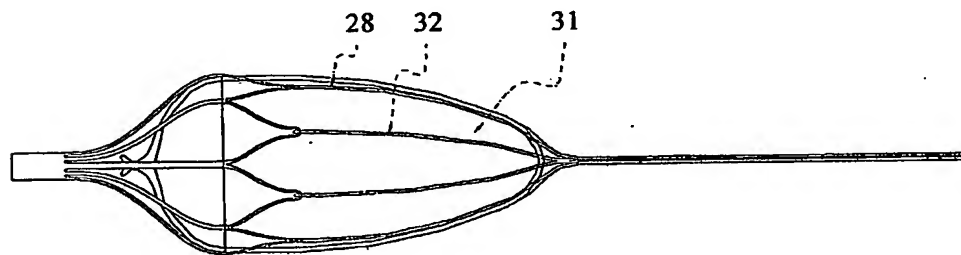


Fig. 4

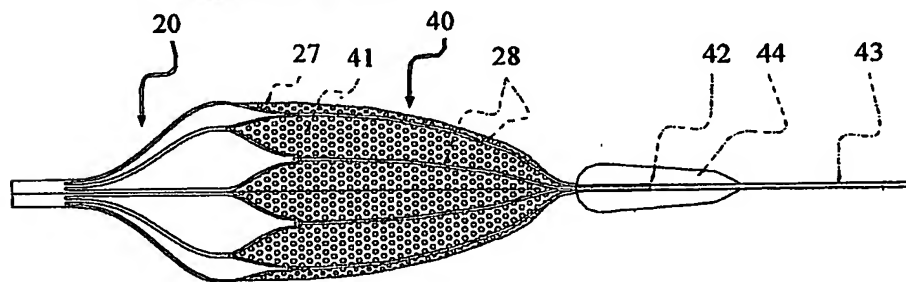


Fig. 5

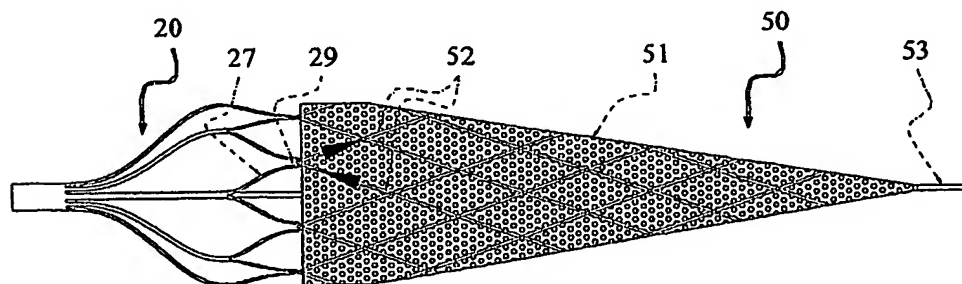


Fig. 6

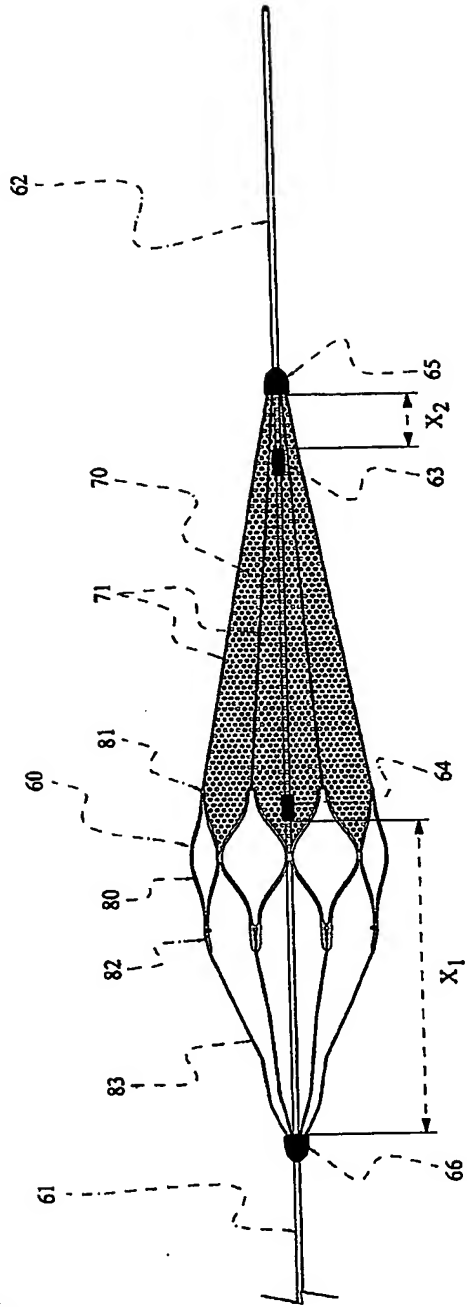
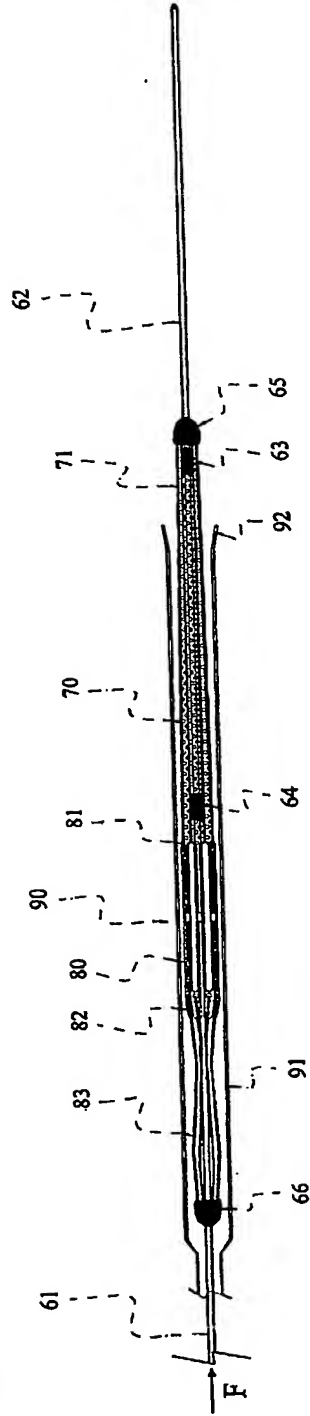


Fig. 7



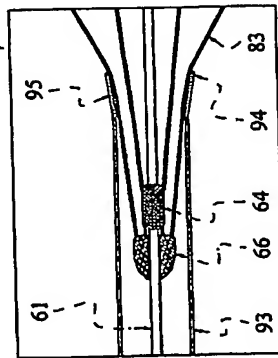
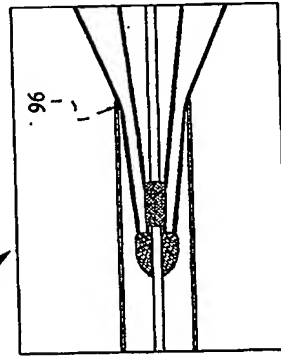
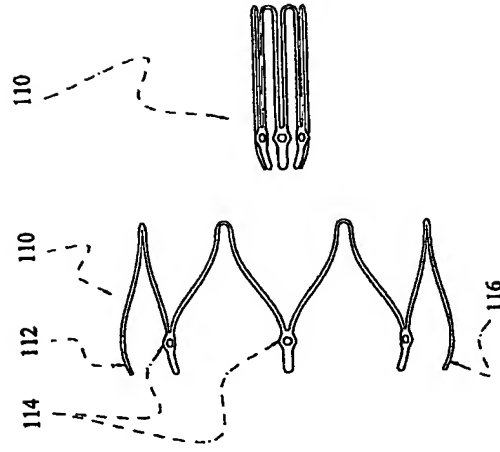
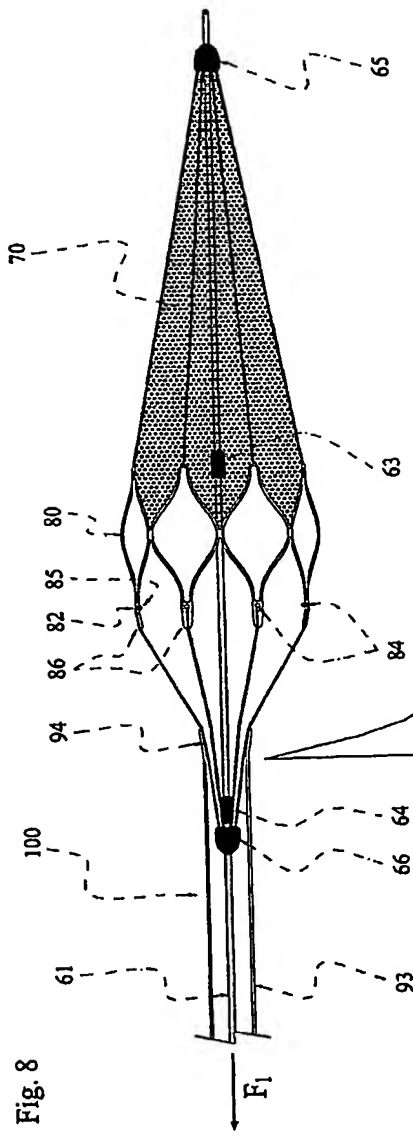
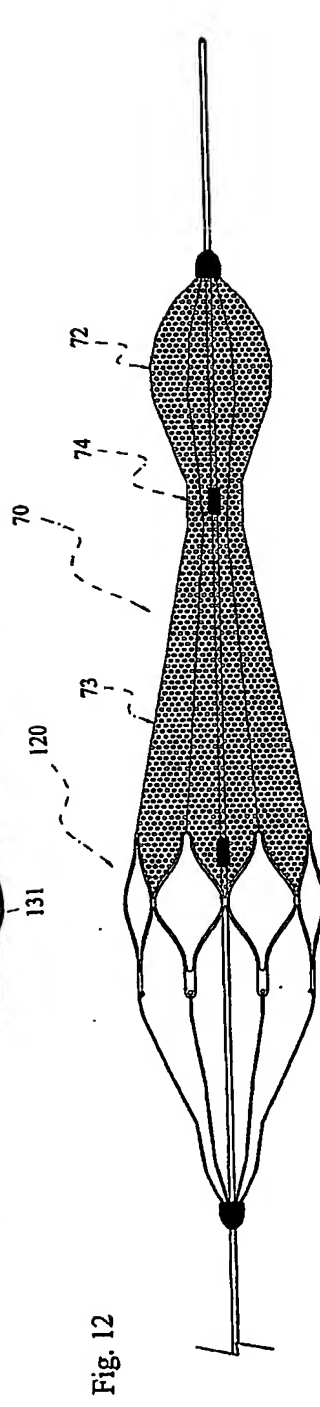
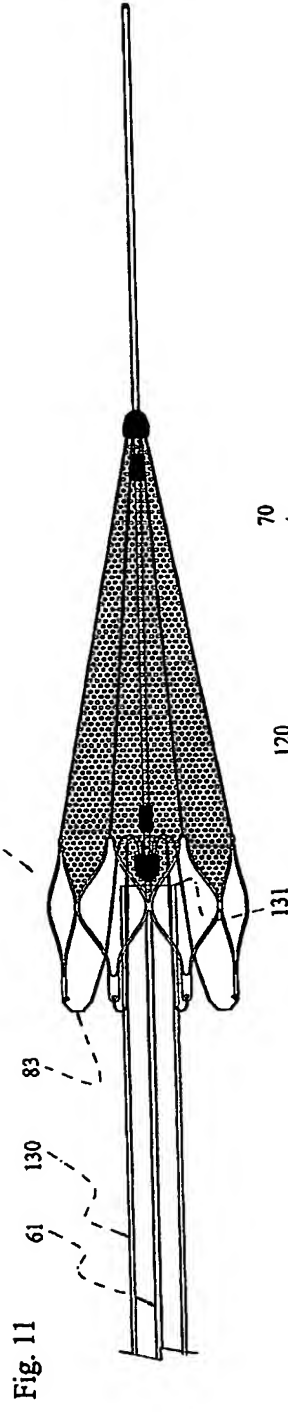
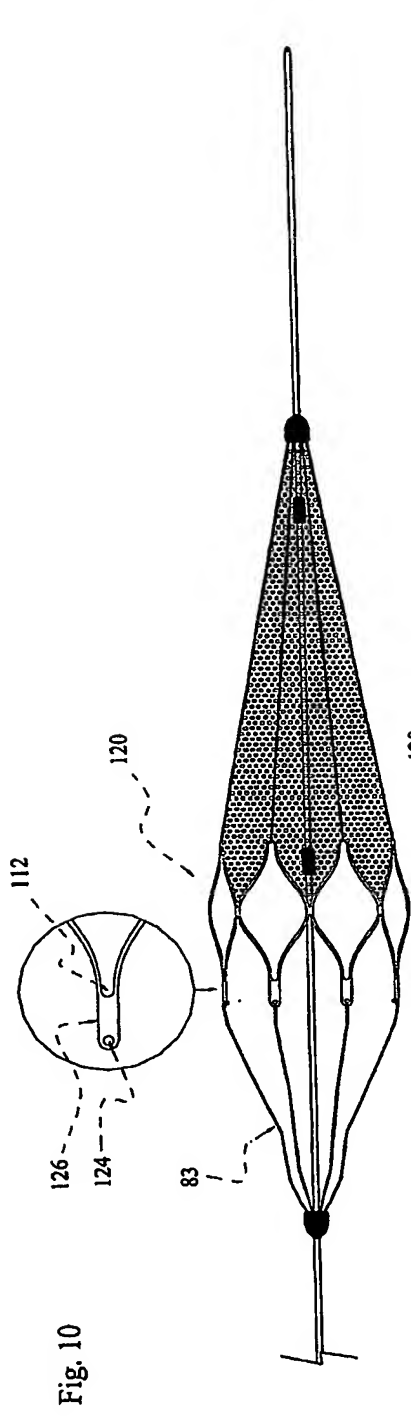


Fig. 8b

Fig. 8a

Fig. 9b

Fig. 9a



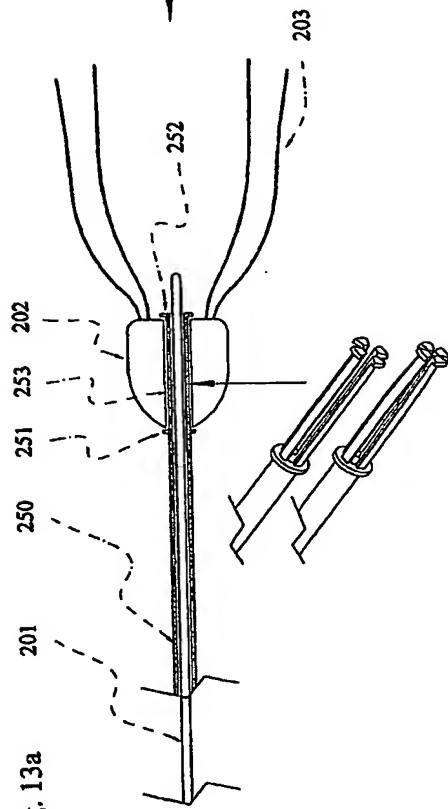
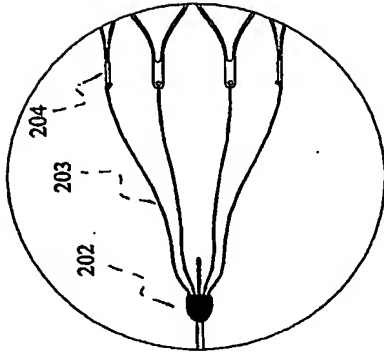


Fig. 13a

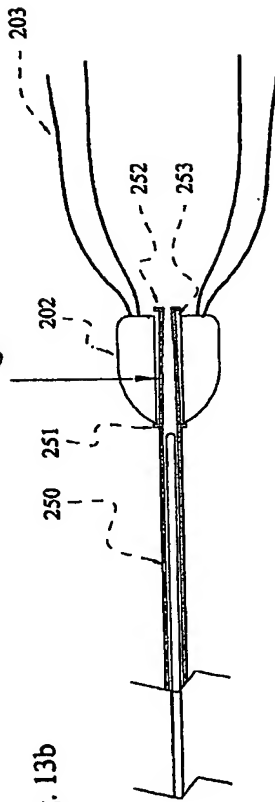


Fig. 13b

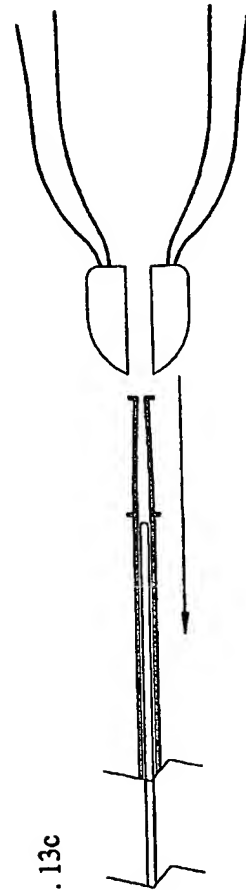


Fig. 13c